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Calibration issues of Tekscan systems for human pressure assessment

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Summary

The Tekscan pressure sensor system has been designed for relatively easy measurement of contact pressures between two opposing surfaces. However, several factors are known to affect Tekscan sensor output. This paper reports on two pilot studies which were done to investigate the effects of contact surface compliance and changes in the system hardware on Tekscan sensor output. In the first study, linear calibration curves were calculated for a single Tekscan sensor array placed on surfaces of varying compliance. The slopes of the curves and variability in both the slopes and intercepts were found to be affected by surface compliance. In the second study, absolute percentage differences in the raw output data bits between a series of Tekscan sensor-cuff combinations were calculated. These differences ranged from 5-32%. The results of these studies indicate that careful attention must be paid to system set-up and calibration when using the Tekscan pressure sensor system to measure contact pressures.

Introduction

An important measure in load carriage studies is the contact pressure experienced by a bearer under the load carriage elements. Previous studies have identified pressure thresholds beyond which there is an increased risk of injury (Holewijn, 1990). Tekscan Inc.[1] has developed a tactile force sensor based on the use of conductive or semi-conductive inks sandwiched between thin, flexible polyester sheets. Electrically conductive pathways are imprinted on the polyester sheets and the conductive ink is deposited between the upper and lower sheets at locations at which the pathways intersect. The ink provides an electrical connection between the upper and lower conductors. The resistance of this connection changes with an applied compressive force. Thus, the Tekscan sensor array comprises a grid of force sensing elements (sensels) which are electrically isolated from each other. Knowing the spatial dimensions and separation of the sensels, the measured force data can be converted into a pressure profile. By varying the spacing and patterns of the conductive pathways, Tekscan has produced an array of sensors of various shapes, sizes and sensel resolution.

The Tekscan pressure measurement system offers a convenient method for measuring contact pressures between two opposing surfaces. The sensors are very thin and flexible and will conform to contoured surfaces. The system is supplied with dedicated hardware and software to measure the change in resistance with applied force across sensels, digitize the measured signals, transfer the digital data to PC and display the measured data as a dynamic pressure profile. In comparison with other contact pressure measurement systems, it is relatively cost-effective. For these reasons, the Tekscan system was adopted by the Ergonomics Research Group, Queen's University, to measure contact pressures under load carriage elements on the Load Carriage Simulator (Bossi et al., 2000). However, there are several factors which are known to affect Tekscan sensor output and, consequently, the accuracy of the reported pressure measurement. These factors include: variations in sensitivity across individual sensels; creep in the output with constant applied pressure over time, leading to hysteresis in the dynamic response; temperature; contact surface curvature; contact

[1] Information on Tekscan products can be obtained at www tekscan.com.

surface compliance and noise introduced by the system hardware (Bryant et al., 1999; Luo et al., 1998; Sumiya et al., 1998; Woodburn and Helliwell, 1996; McNeil, 1996).

This paper reports on two studies, which were done to investigate the effects of the last two factors on the measured output and calculated calibration curves of specific Tekscan sensor arrays. In the first study, calibration of the same Tekscan 9811 sensor array was performed with the array placed on surfaces of varying compliance. In the second study, F-scan sensor output was measured for several sensor-cuff combinations and for the sensors connected to the cuff in the normal and inverted orientations.

Methodology

The Influence of Contact Surface Compliance

Calibration curves were calculated for a single Tekscan 9811 sensor. The sensor comprises 96 sensels arranged in a 16×6 rectangular grid. Sensels are spaced 12.7 mm apart; the active area of each sensel is the 6mm × 7mm region in the centre of the effective sensel area, which is 12.7mm × 12.7mm or 161 mm^2. The dynamic range of the 9811 sensor is 1-500kPa.

Calibrations were performed using two calibrators: a flat, bladder calibrator and a hand-held calibrator. The flat bladder calibrator is comprised of two metal plates. The lower plate is covered in latex rubber and the Tekscan sensor array is laid over this plate. An inflatable latex rubber bladder is placed over the Tekscan array, such that it covers the entire array, and the upper plate is secured over the bladder. Constant pressure is applied across all sensels by inflating the bladder. The pressure level is read on the attached gauge. The hand-held calibrator (Bryant et al., 1999) applies a controlled force at the tips of four variable displacement pistons. The applied force is linearly related to a known pressure applied to the pistons. The centre-to-centre spacing of the pistons is the same as the sensel spacing in the 9811 sensor. The tips of the pistons are rounded to avoid edge effects. The hand-held calibrator activates four sensels at a time, and is moved across the sensor to calibrate the entire array.

The 9811 sensor was calibrated under four conditions:

- using the flat bladder calibrator;
- using the hand-held calibrator with the sensor array on a flat, non-compliant surface – the base of the flat bladder calibrator;
- using the hand-held calibrator with the sensor array on a relatively flat, slightly compliant surface – the back of the LC Simulator manikin, which is a rigid surface covered in Bocklite™, a skin analog;
- using the hand-held calibrator with the sensor array on a more compliant surface – the back of a human subject.

On the manikin and the human subject, the sensor array was positioned 3cm to the right of the spinal column, with the lower edge of the sensor at approximately T12. The sensor was activated at four pressures: 10, 20, 30 and 40 kPa using the flat bladder calibrator and 20, 30, 35 and 40 kPa using the hand-held calibrator. The raw output data bits were recorded for 10s at 1 Hz at each applied pressure to obtain ten 16×6 data arrays.

The recorded data were processed to obtain linear calibration curves for individual sensels under each of the four calibration conditions. The recorded output data bits were imported into Excel® and a single array for each pressure was obtained by averaging over the ten recorded arrays. Linear regression was performed across the four data points obtained for each sensel. A set of ninety-six separate calibration curves was obtained for each calibration condition. These curves were compared to assess the differences in the calibration of the 9811 sensor under the four separate conditions.

The Influence of the Tekscan Cuff

The F-scan in-shoe sensor was used in this study, since the F-scan sensor can be connected to the cuff in two orientations: normal and inverted, whereas the 9811 sensor can only be connected in one orientation. The F-scan sensor array contains 960 sensels arranged in a grid pattern with a spatial density of 4 sensels/cm^2. The dynamic range of the F-scan sensor is 1-150 psi (approximately 7-1000 kPa).

The F-scan sensor was placed in the flat bladder calibrator and connected to a Tekscan cuff in the normal orientation. A constant 40kPa pressure was applied and 21 frames of data were collected over 2s. The F-scan sensor connection was then inverted in the cuff and another 21 frames of data were collected. The procedure was repeated for two more F-scan sensors, using the same cuff and for the F-scan sensors using each of three different cuffs. The average absolute percentage difference was calculated for each pair of normal versus inverted output data bits and for output data bits collected from different sensor-cuff combinations. The absolute percentage difference was calculated using the absolute values of the differences in the output data bits.

Results

The Influence of Contact Surface Compliance

The slopes and intercepts of the linear calibration curves calculated for the individual sensels were averaged for each calibration condition. The averages, standard deviations and coefficients of variation are given in Table 1. The slopes for the individual calibration curves are plotted as bar graphs in Figure 1. It can be seen that the flat bladder calibrator gives the lowest calibration slopes and the lowest variation in the slopes. The average slope increases when the hand-held calibrator is used on the Tekscan sensor placed on the flat non-compliant surface. The slope decreases as the hand-held calibrator is used on more compliant surfaces, but the average slopes are still greater than the average slope for the flat bladder case. In all cases the average intercept is close to zero. As the surface compliance increases, the variability in both the slope and the intercept increases.

Table 1. Statistics for the slopes and intercepts* of the calibration curves calculated under the four calibration conditions

Calibration condition	Slope			Intercept		
	Average	Std. Dev.	Coeff. Var.	Average	Std. Dev.	Coeff. Var.
Flat bladder	0.243	0.036	0.148	0.43	0.804	1.87
Flat hand-held	0.331	0.085	0.257	-0.827	2.119	2.562
Manikin hand-held	0.289	0.115	0.398	-0.738	2.724	3.691
Human hand-held	0.262	0.165	0.630	0.249	4.526	18.177

*Slopes are in raw data bits/kPa; intercepts are in raw data bits

The calibration curves for each of the four conditions were used to calibrate a single pressure map obtained from a Tekscan 9811 sensor affixed to the mid-back of a human subject as the subject performed a range of motion task while wearing a loaded backpack. The resulting pressure maps are shown in Figure 2. The variability in reported pressure using the different calibration curves is obvious.

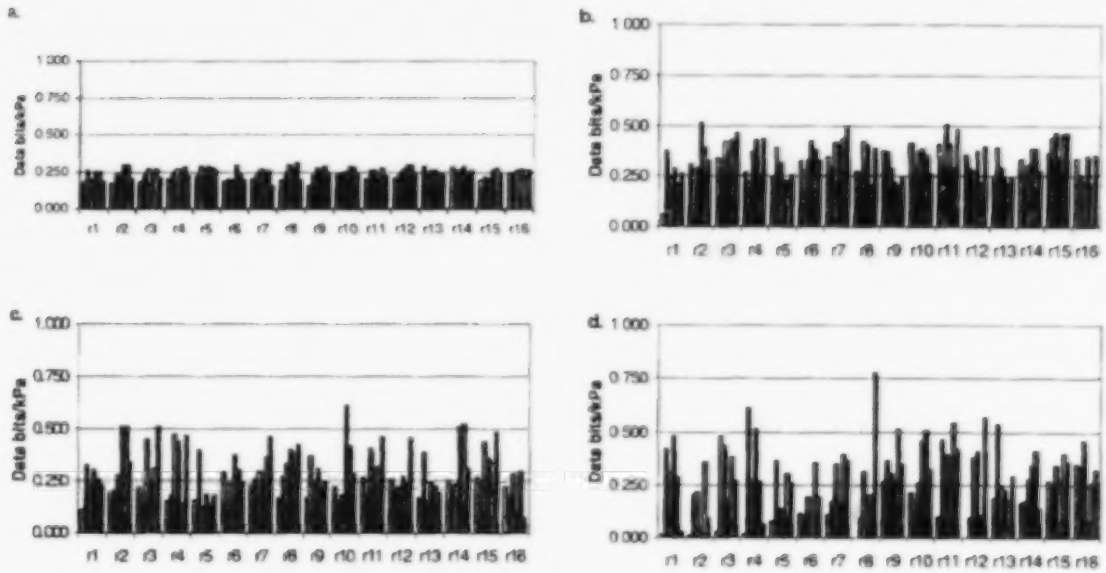

Figure 1. Linear calibration curve slopes for individual Tekscan sensels calibrated under four separate conditions: a. flat bladder calibrator; b. in-situ calibrator used on a non-compliant surface; c. in-situ calibrator used on a slightly compliant surface (the back of the LC manikin); d. in-situ calibrator used on a more compliant surface (the back of a human subject). r1 – r16 indicates row 1 to row 16; each row contains six sensels.

The Influence of the Tekscan Cuff

Table 2 summarizes the absolute percentage differences obtained for the various test conditions: normal versus inverted sensor-cuff orientation; changing cuffs; and changing sensors. In several cases, absolute percentage differences greater than 10% were obtained. In two cases, absolute percentage differences greater than 30% were obtained.

Table 2. Statistics for percent differences between F-scan data collected under different sensor-cuff orientations and combinations.

Condition		Absolute Percent Difference		
		Average	Std. Dev.	Coeff. Var.
Normal vs. Inverted Cuff Orientation		12.63	0.43	0.03
Changing FScan Cuffs (3)	Sensor 1	13.04	6.43	0.49
	Sensor 2	6.86	3.16	0.46
	Sensor 3	5.00	1.90	0.38
Changing FScan Sensor (4)	Cuff 1 (constant)	16.09	5.29	0.33
	Cuff 2 (constant)	15.14	3.26	0.22
	Cuff 3 (constant)	30.46	14.57	0.48
	Cuff 4 (constant)	32.69	17.25	0.53

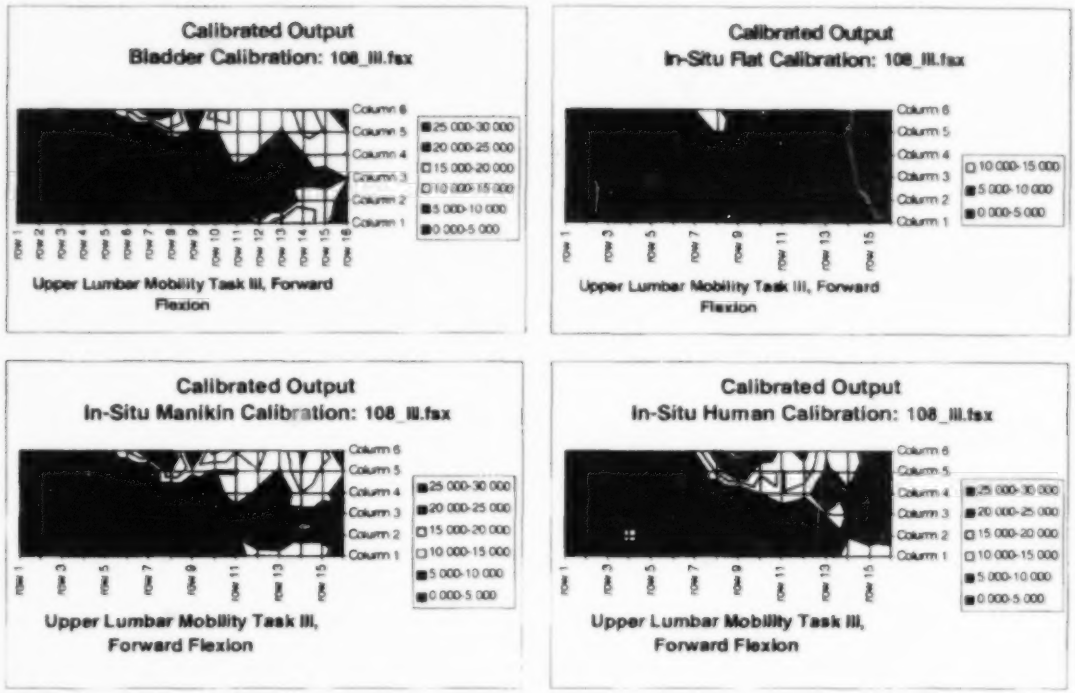
Calibrated Output
Bladder Calibration: 108_III.fsx
Upper Lumbar Mobility Task III, Forward Flexion
Calibrated Output
In-Situ Flat Calibration: 108_III.fsx
Upper Lumbar Mobility Task III, Forward Flexion
Calibrated Output
In-Situ Manikin Calibration: 108_III.fsx
Upper Lumbar Mobility Task III, Forward Flexion
Calibrated Output
In-Situ Human Calibration: 108_III.fsx
Upper Lumbar Mobility Task III, Forward Flexion

Figure 2. Tekscan pressure distribution maps for a single recording calibrated using each of the four sets of calibrations curves. The Tekscan sensor was affixed to the back of a human subject who was wearing a loaded backpack. The recording was made while the subject performed forward flexion at the hips.

Discussion

As noted above, the slope of the linear calibration curve decreases as the compliance of the surface under the Tekscan sensor increases, when using the hand-held calibrator. The lowest and most consistent calibration slopes, however, were obtained using the flat bladder calibrator, where a constant pressure was applied across all sensels.

Using the hand-held calibrator, calibration slopes and sensor outputs are lower for the Tekscan sensor located over more compliant surfaces. This agrees with results reported by Luo et al. (1998), who found that Tekscan sensor output increased with increased surface hardness. In our case, the decrease in sensor output can be, at least partially, explained by the fact that the compliant material under the Tekscan sensor and the sensor itself will deform under the piston when force is applied. Some of the reaction force under the piston, then, will occur around the curved edge of the contacting surface of the piston. This force will have a shear, as well as a compressive component, and the direct force experienced by the Tekscan sensel will be lower, hence a lower sensel output. It is important to recognize that a shear force component can exist in compliant material, and have an effect on the pressure measurement reported by Tekscan.

Luo et al. (1998) also reported that the pressure distribution recorded from the F-scan sensor was more uniform when pressure was applied over a softer surface. In the present study, however, the variation in the calibration slopes and output data bits across sensels was found to increase as the surface compliance

increased. In Luo et al.'s study, an F-scan sensor was sandwiched between two surfaces, (configured as hard-hard, hard-soft and soft-soft), and a pressure of 193 kPa was applied uniformly over the sensor. This is quite different from the present study, in which a controlled force was applied to the central regions of four individual sensels using the hand-held calibrator. A compliant material under the sensor will deform with the applied force and because the sensor itself is flexible, it too will deform. The effect of such deformations on the Tekscan output is not well understood, but may be a source of inter-sensel variations. Another source of variability is the non-uniformity of the compliant surfaces. Neither the LC manikin nor the human provides a perfectly flat surface covered in a uniform thickness of compliant material. Variations in the surface contours and the Bocklite thickness on the manikin would contribute to variation in the Tekscan output. And in the human, variable compliance between regions supported by bone and those supported by soft tissues, results in variations in the pressure distribution across the surface.

Another source of variability in the reported results arises from the limited pressure range over which the Tekscan sensor was calibrated. Calibration data were recorded for pressures from 10 – 40 kPa. The Tekscan 9811/50/75 sensor has a dynamic range of 1 – 500 kPa. Working within a limited portion of the output range results in increased errors due to limited cell resolution (Luo et al., 1998). However, pressures experienced under well-designed load carriage elements (e.g. backpack shoulder straps and waistbelts) have been found to rarely exceed 40 kPa (Bryant et al.,1997). Calibration at these low pressures is important in applying Tekscan sensors to evaluate contact pressures experienced during load carriage.

In the second study reported here, it was found that reported pressures are affected by the hardware used (sensor array and cuff) and by the orientation of the connection between the sensor and the cuff for the F-scan sensor system. The absolute precentage differences obtained in this pilot study were found to range from 5-32%. These results attest to the importance of keeping the Tekscan set up consistent throughout the duration of an experiment.

The results of the two studies reported here indicate that the Tekscan sensor system must be carefully calibrated to obtain the best results in terms of accuracy and repeatability. Calibration should be performed under conditions that are as close as possible to the actual measurement conditions. Tekscan sensors have a limited lifetime and should be tested and replaced regularly. Tekscan cuffs should be put through regular maintenance cycles and re-calibrated after maintenance. The Tekscan sensor system has many advantages for use in measuring surface contact pressures. However, in the absence of a gold standard, accurate calibration of the Tekscan system remains a challenge and a good understanding of the factors which affect Tekscan sensor performance and contribute to variability in the output is essential.

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References

BOSSI, L., STEVENSON, J.M., BRYANT, J.T., PELOT, R., REID, S. and MORIN, E., Development of a suite of objective biomechanical measurement tools for personal load carriage equipment assessment, *NATO-RTO Conference on Soldier Mobility: Innovations in Load Carriage System Design and Evaluation*, Kingston, Ont. 27-29 June, 2000.

BRYANT, J.T., REID, S.A. and STEVENSON, J.M., Contact Pressure Calibration Method: Development of a Calibration Jig, *DCIEM Contractor Report* (unpublished), submitted in partial fulfillment of PWGSC Contract No. W7711-7-7405/SRV. Report submitted to the Defence and Civil Institute of Environmental Medicine, March, 1999.

BRYANT, J.T., STEVENSON, J.M., PELOT, R.P., MORIN E., DEAKIN, J.M., REID, S.A. and DOAN, J.B., Research and Development of an Advanced Personal Load Carriage System (Phases II and III), *DCIEM Contractor Report* (unpublished), submitted in partial fulfillment of PWGSC Contract No. W7711-5-7273/001/TOS, Report submitted to the Defence and Civil Institute of Environmental Medicine, Feb., 1997.

HOLEWIJN, M., Physiological strain due to load carrying, *Eur. J. Appl. Physiol.*, 61: 237-245, 1990.

LUO, Z.P., BERGLUND, L.J. and AN, K.N., Validation of F-scan pressure sensor system: a technical note, *J. Rehab. Res. Devel.*, 35: 186-191, 1998.

McNEIL, S.K., Validation and Development of a Mathematical Model of the Shoulder for Load Carriage, *M.Sc. thesis, Dept. of Physical and Health Education, Queen's University, Kingston, Ont.*, 1996.

SUMIYA, T., SUZUKI, Y., KASAHARA, T. and OGATA, H., Sensing stability and dynamic response of the F-scan in-shoe sensing system: A technical note, *J. Rehab. Res. Devel.*, 35: 192-200, 1998.

WOODBURN, J. and HELLIWELL, P.S., Observations on the F-scan in-shoe pressure measuring system, *Clin. Biomech.*, 11:301-304, 1996.

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